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(54) **SULFUR-IMPREGNATED AND COUPLING
AGENT-REACTED ORGANOCCLAY
MERCURY AND/OR ARSENIC ION
REMOVAL MEDIA**

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patent is extended or adjusted under 35
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claimer.

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(52) **U.S. Cl.** **502/80**; 502/85; 502/400;
502/401; 502/417

(58) **Field of Classification Search** 502/80,
502/85, 400, 401, 417
See application file for complete search history.

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(57) **ABSTRACT**

The use of two mercury and arsenic removal media: A) a
sulfur-impregnated organoclay; and B) a coupling agent-re-
acted organoclay, wherein the coupling agent preferably con-
tains a mercapto, disulfide, tetrasulfide and/or polysulfide
end group provides mercury removal media having increased
reactivity, stability, and synergistic mercury removal ability.
The preferred mercury removal media described herein is
prepared by reacting an organophilic clay containing onium
ions A) with elemental sulfur; and B) with a sulfur-containing
coupling agent, preferably containing a mercapto, disulfide,
tetrasulfide, and/or polysulfide moiety.

7 Claims, 11 Drawing Sheets

Figure 1

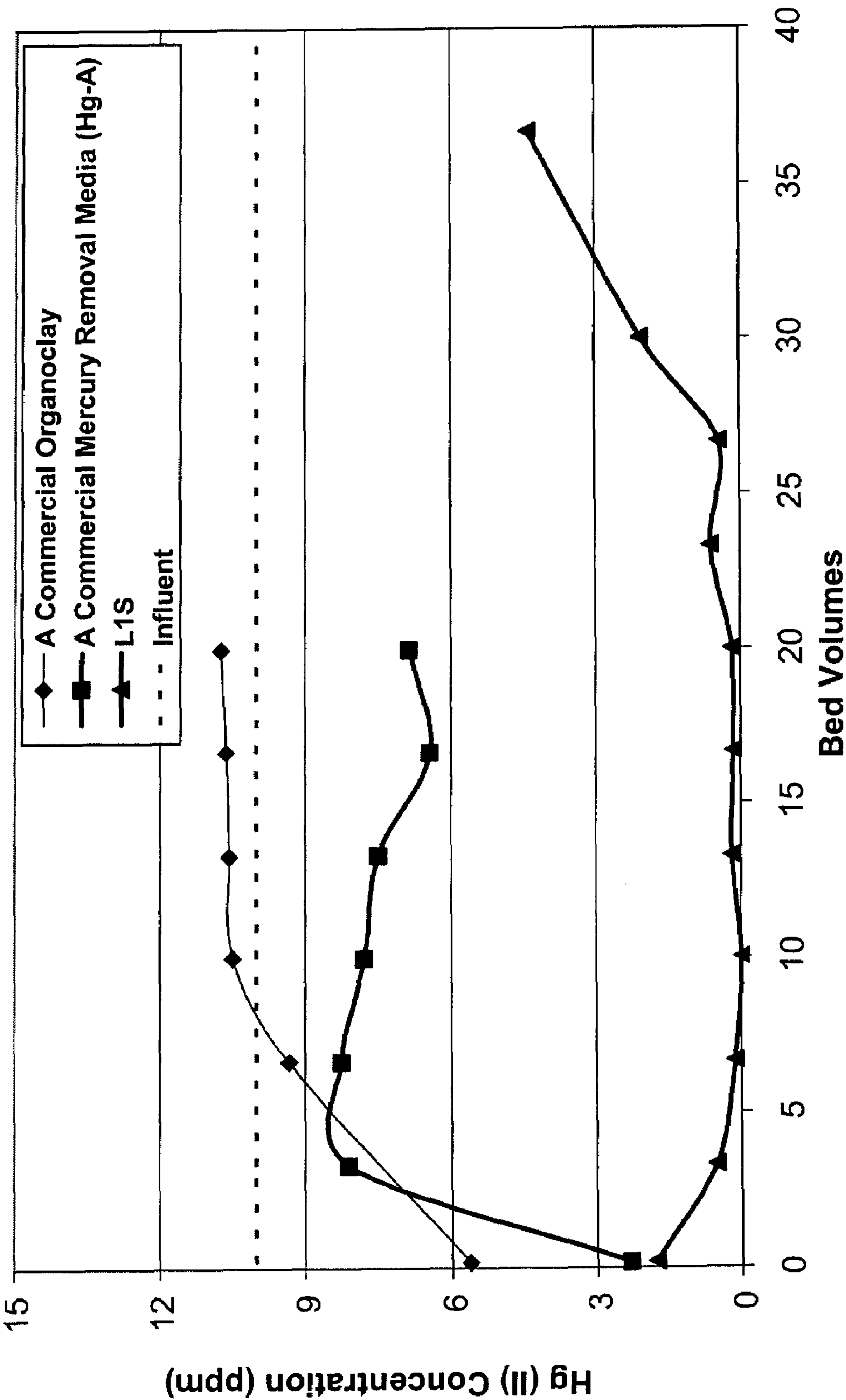


Figure 2

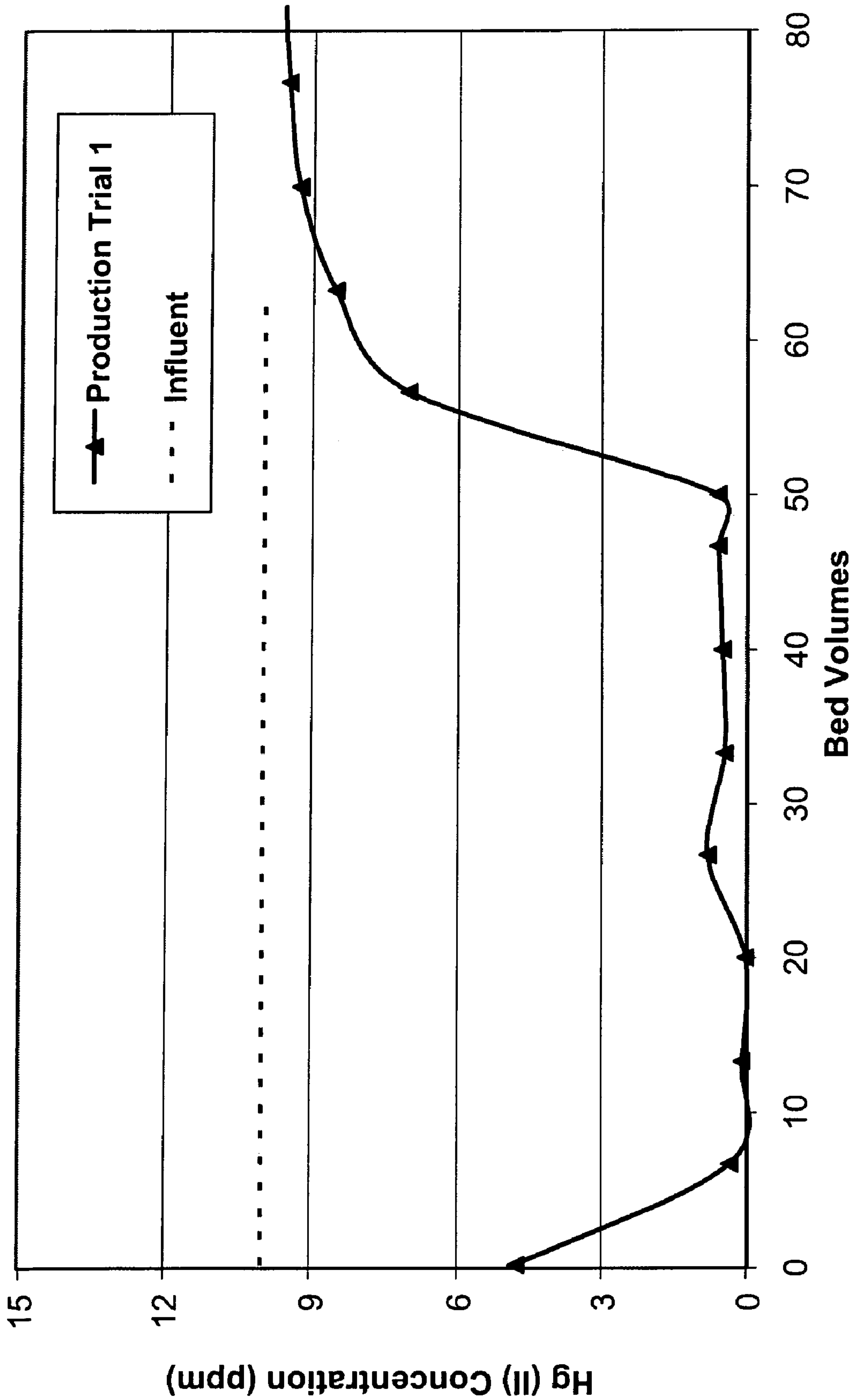


Figure 3

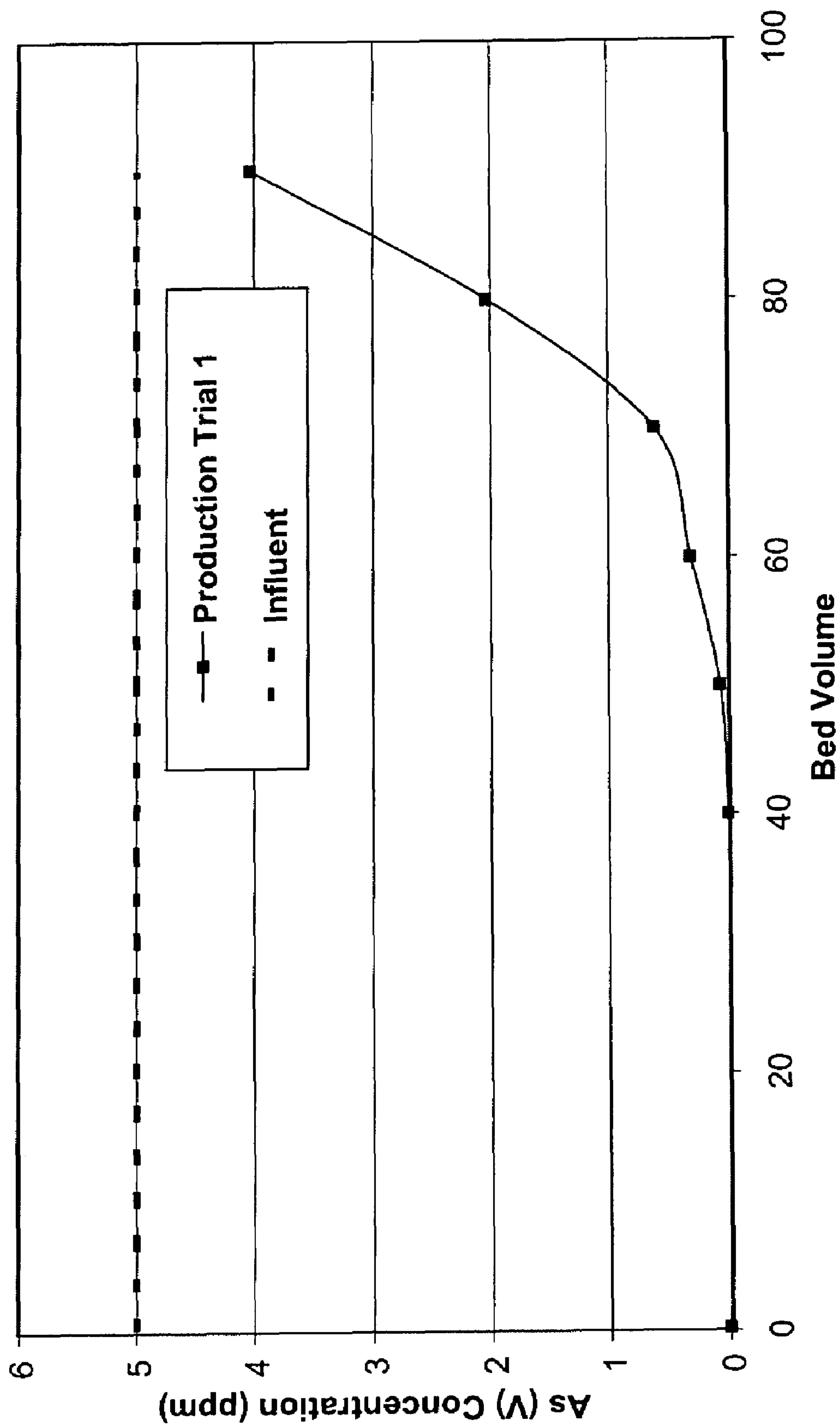


Figure 4

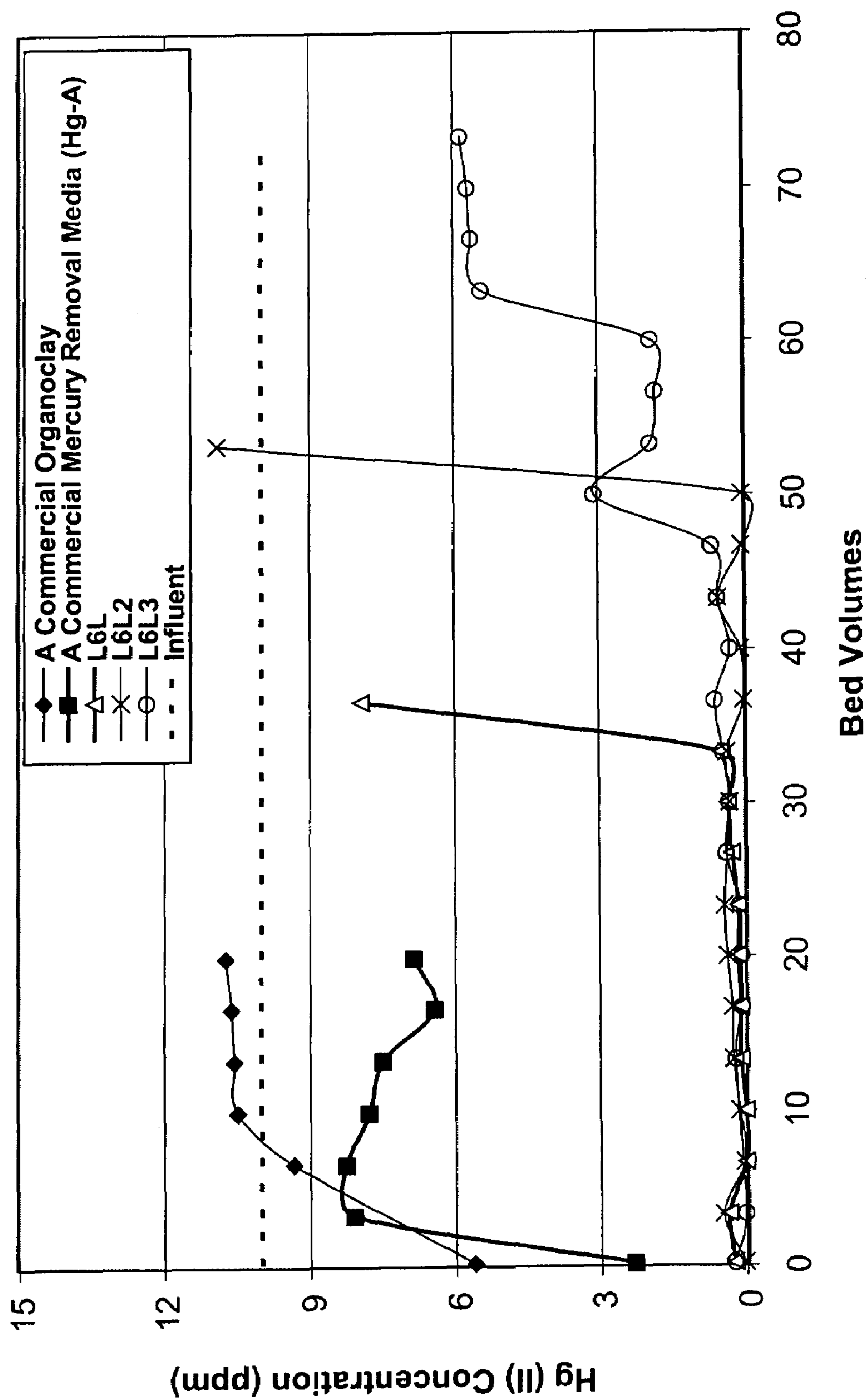


Figure 5

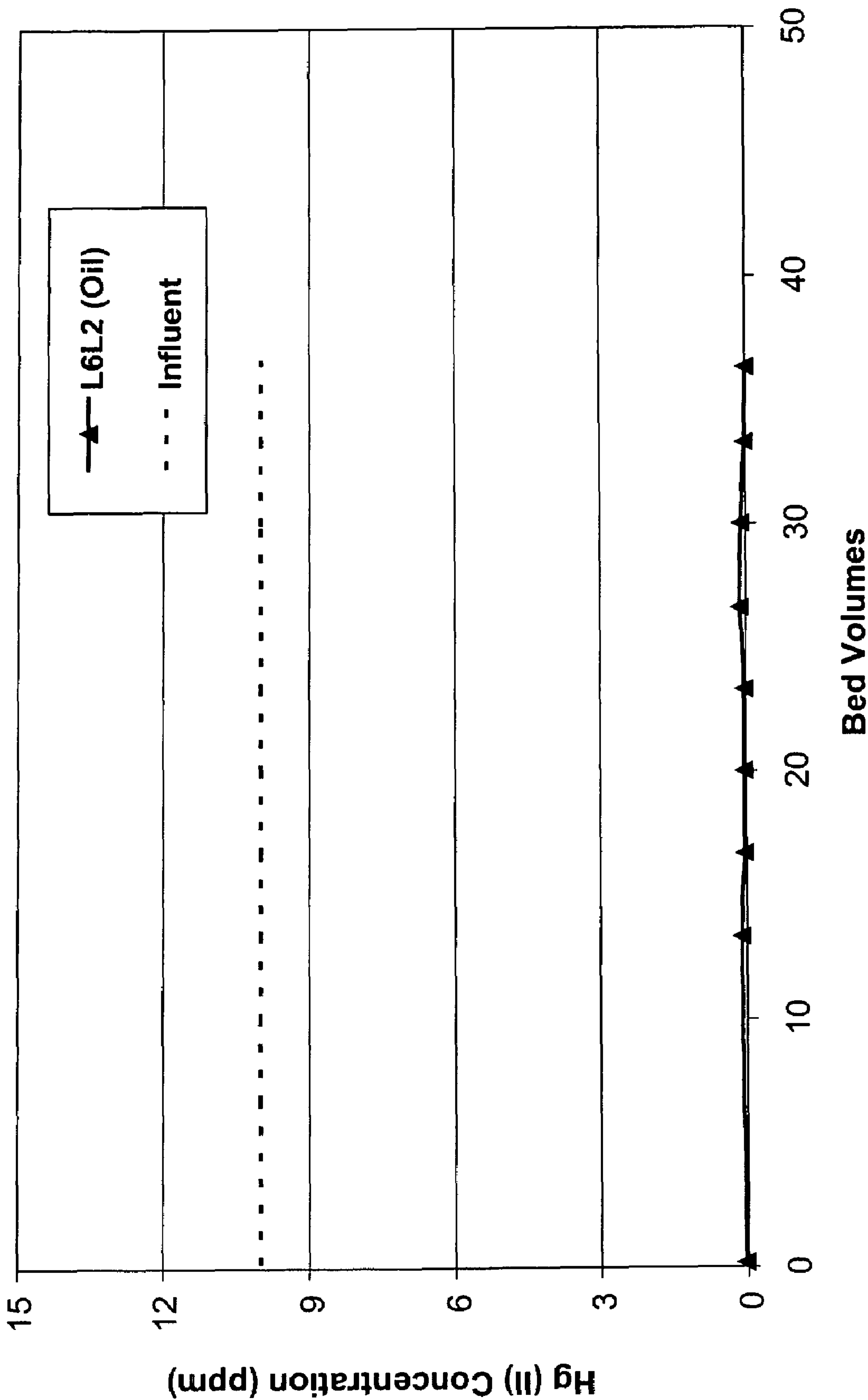
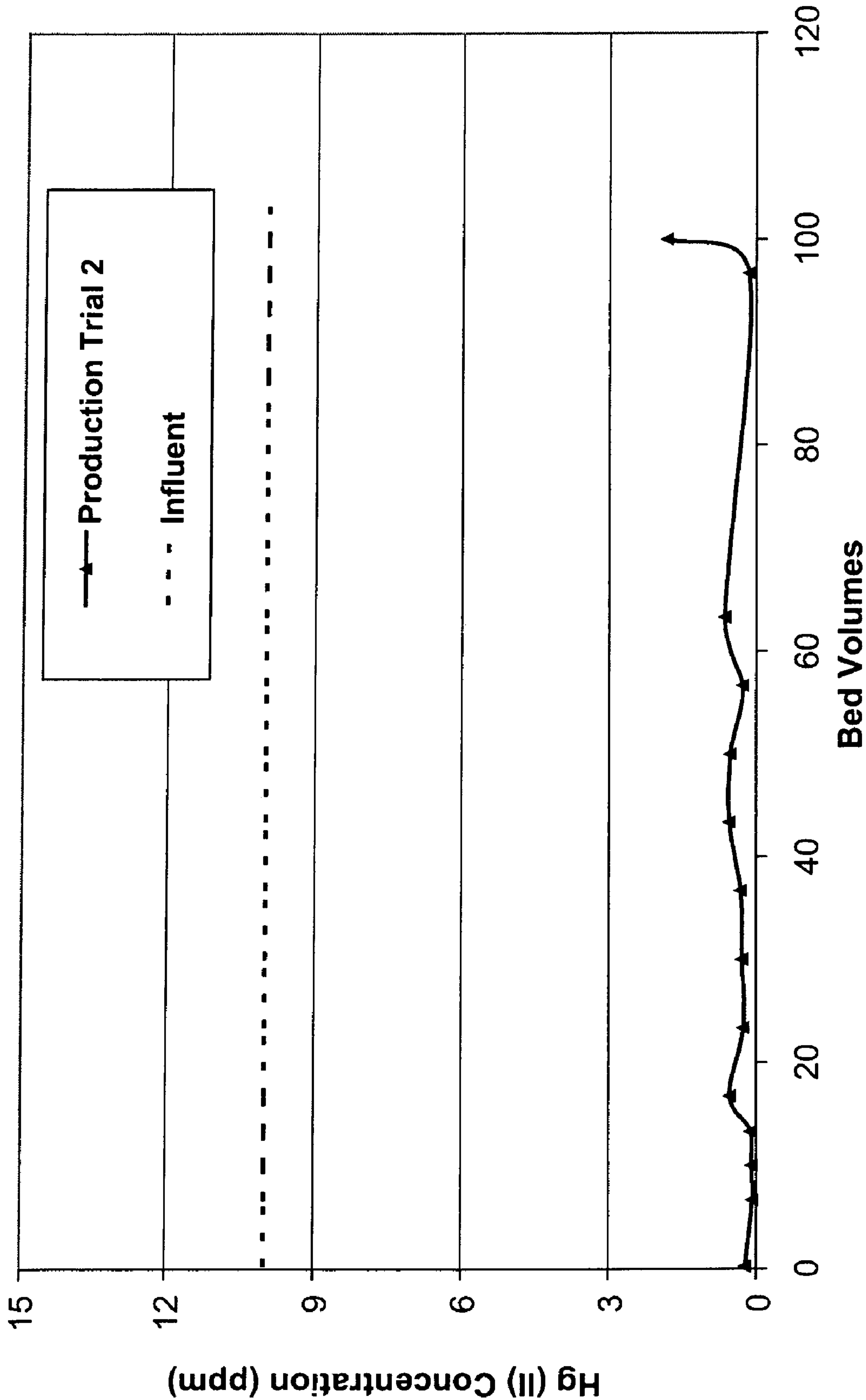


Figure 6



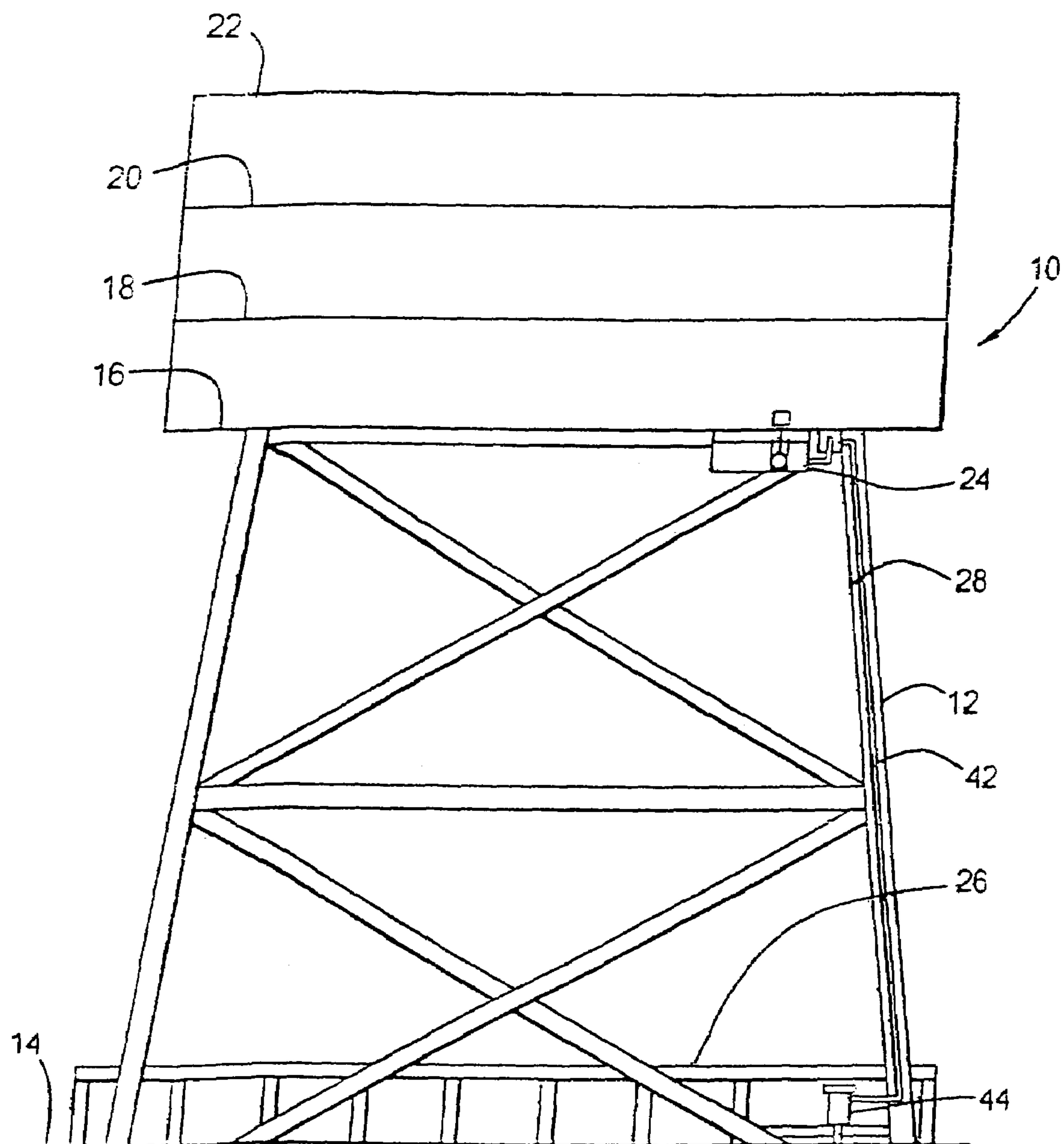


FIG. 7

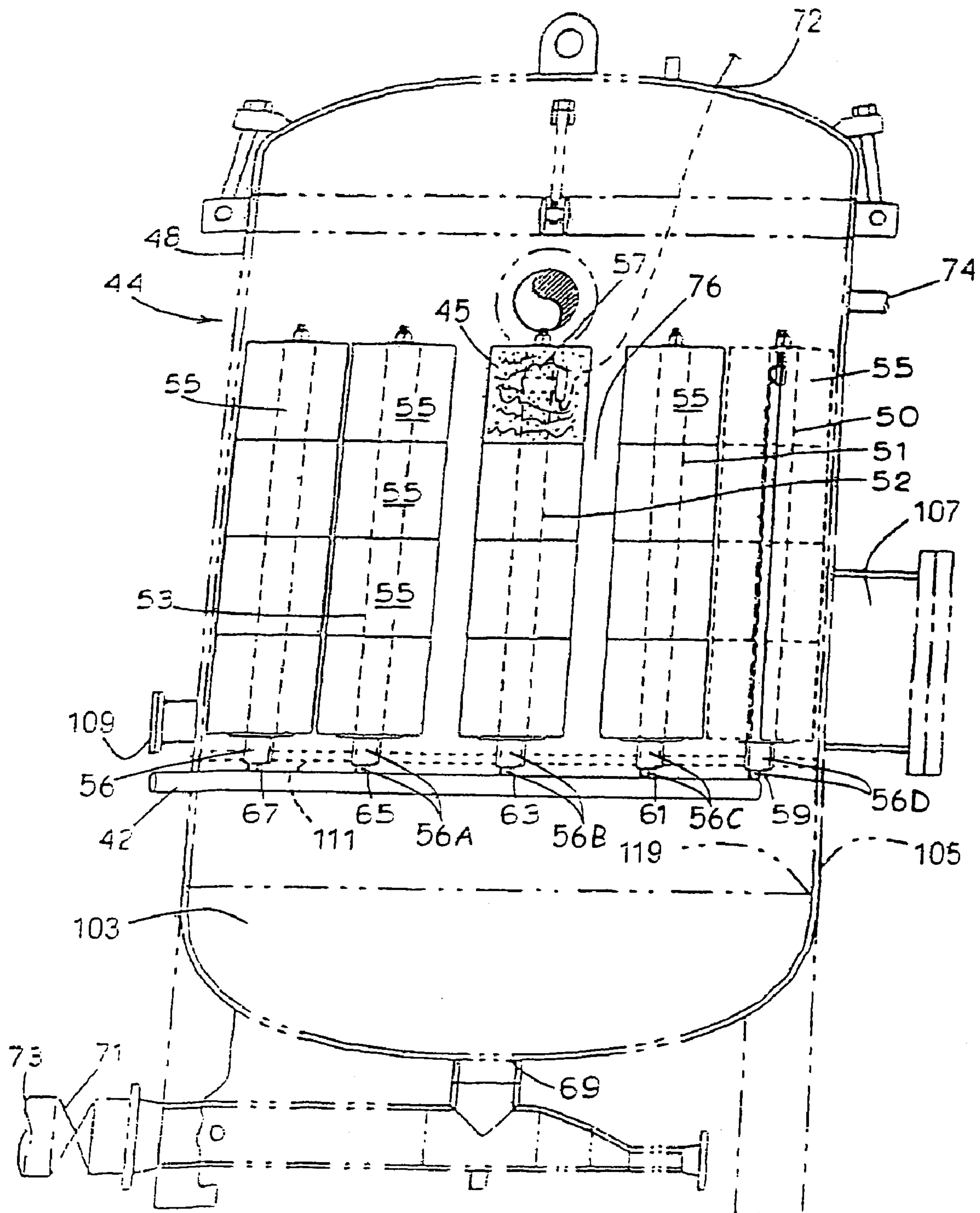


FIG. 8

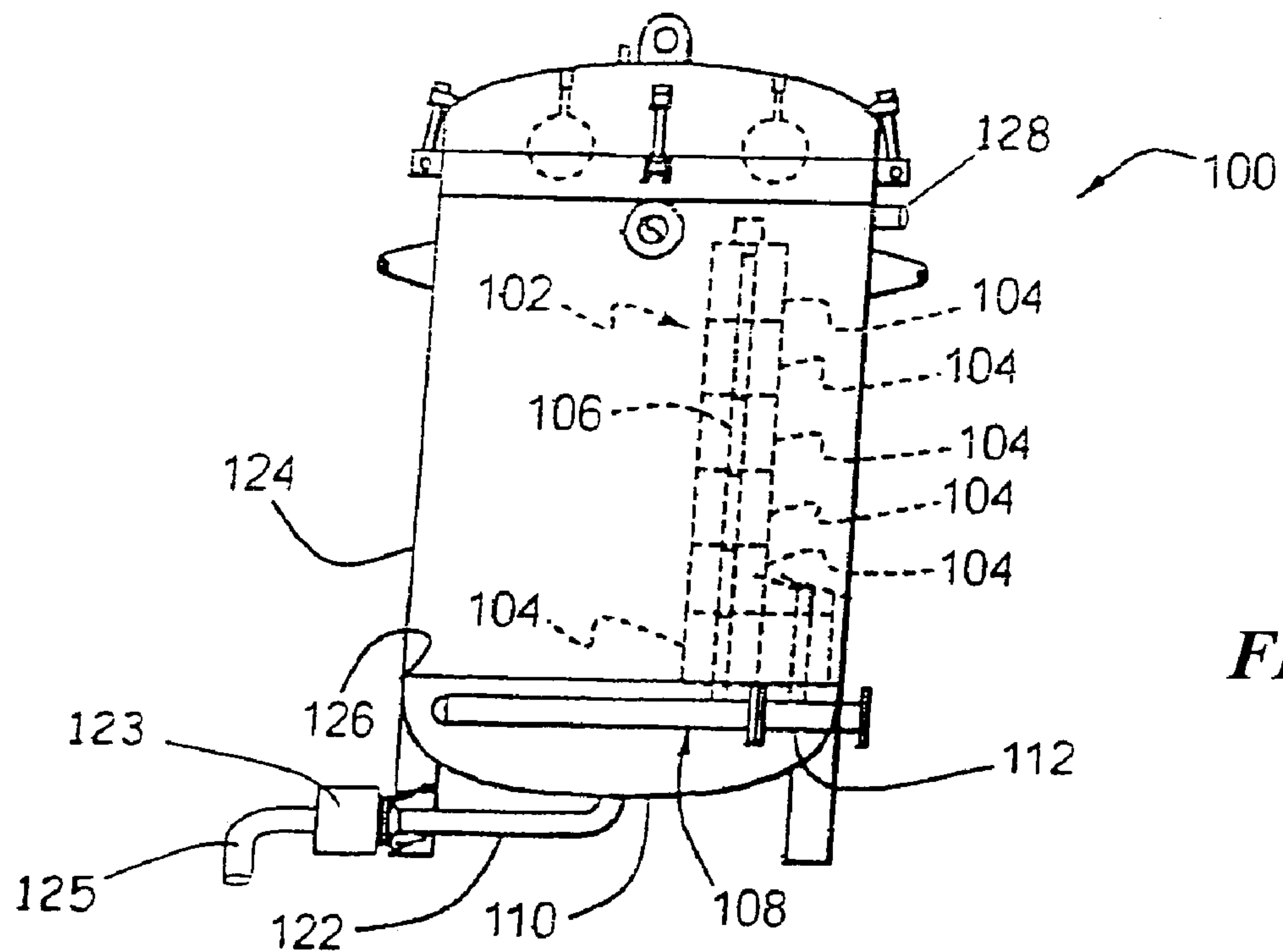


FIG. 9

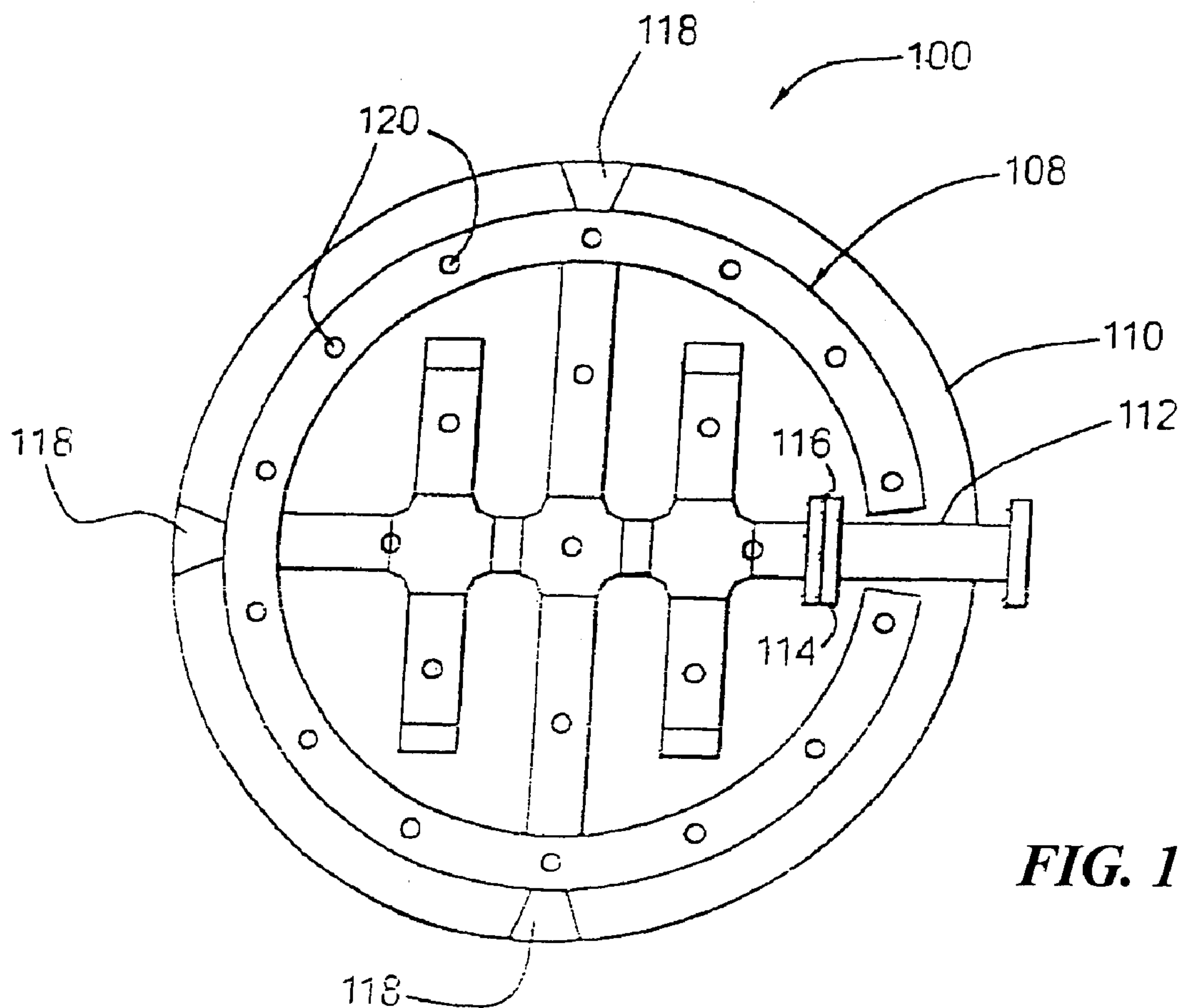


FIG. 10

FIG. 11

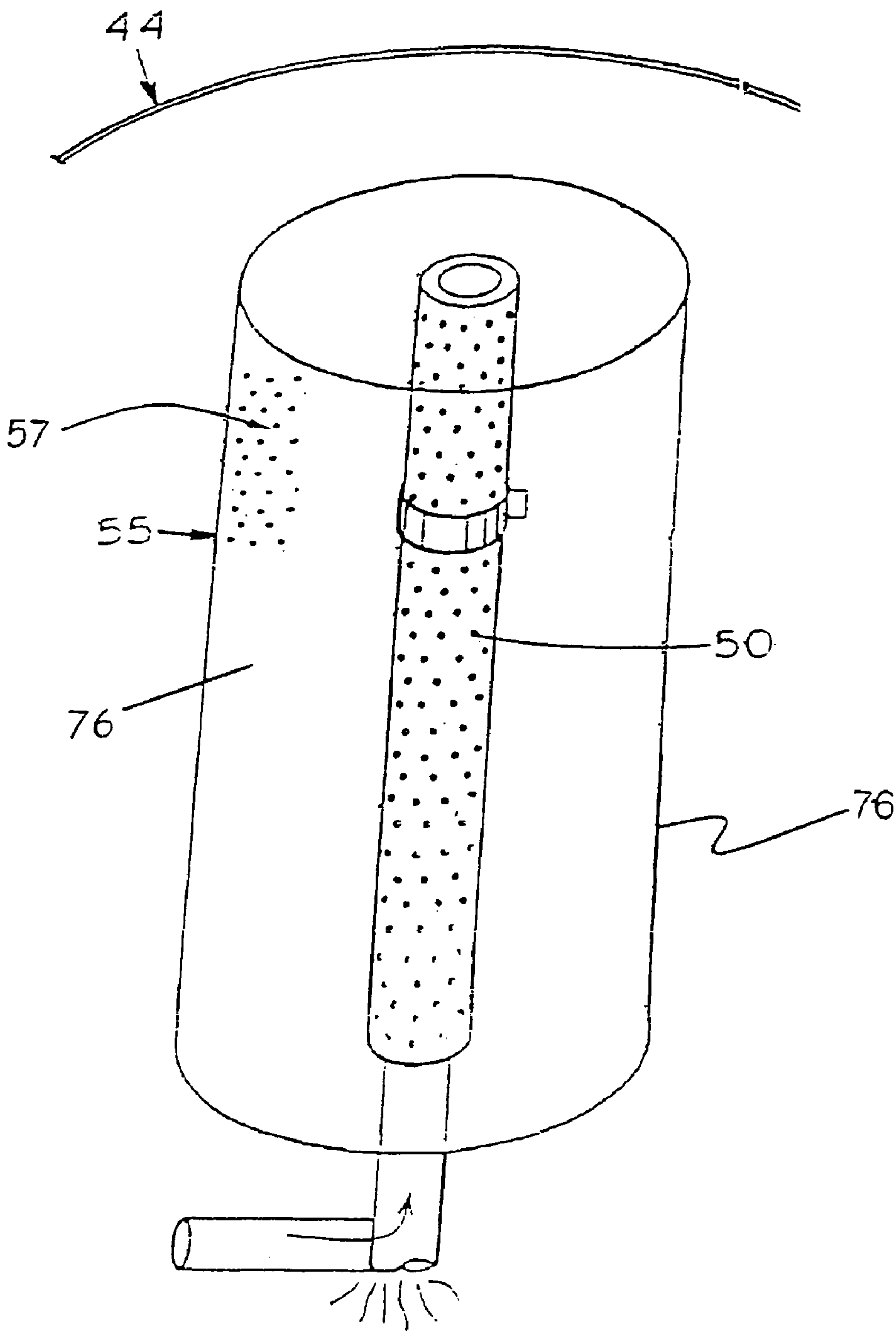
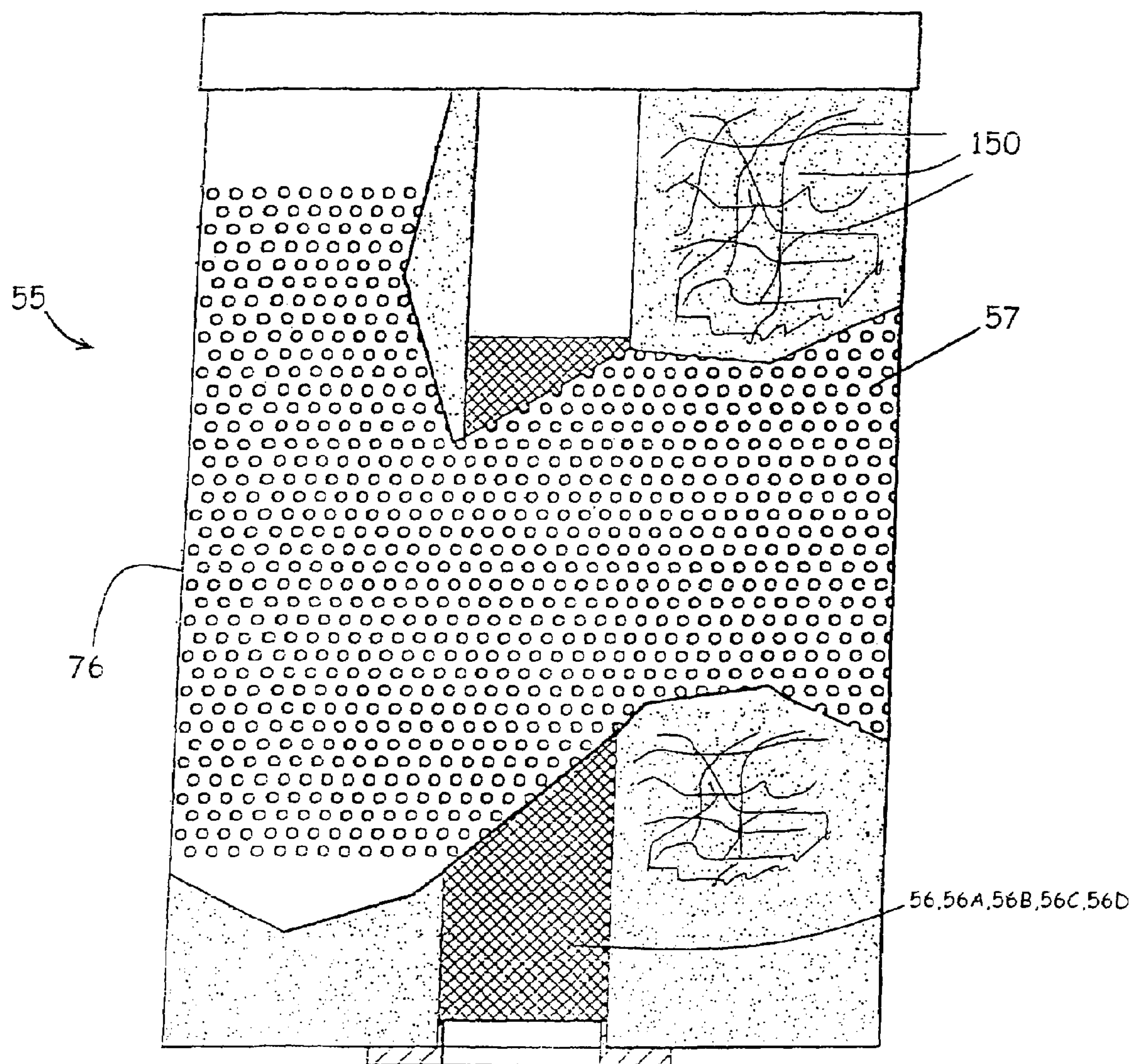


FIG. 12



**SULFUR-IMPREGNATED AND COUPLING
AGENT-REACTIONED ORGANOCCLAY
MERCURY AND/OR ARSENIC ION
REMOVAL MEDIA**

FIELD OF THE INVENTION

The present invention is directed to compositions; methods of manufacturing the compositions; and methods of using the compositions for removing mercury (organic mercury, Hg, Hg⁺; and/or Hg⁺²) and/or arsenic (As⁺³ and/or As⁺⁵) from water. The compositions, also identified herein as “media”, or “mercury removal media”, or “arsenic removal media”, or “Hg/As removal media”, can be used to remove mercury and/or arsenic from any water source and is particularly useful for removal of mercury and/or arsenic from drinking water; industrial wastewater; contaminated groundwater; contaminated sediment; offshore produced water, so that the produced water can be returned to the ocean; and for removal of mercury and/or arsenic from aqueous mining wastes. The Hg/As removal media comprises a combination of two Hg/As removal media: (1) a homogeneous, preferably extruded composition comprising a layered phyllosilicate, elemental sulfur (free state sulfur), and an organic phyllosilicate surface treating agent, preferably an onium cation, resulting in an organoclay containing sulfur and (2) a homogeneous, preferably extruded composition comprising a layered phyllosilicate coupled to a coupling agent containing a mercapto or sulfide reactant group, and an organic phyllosilicate surface-treating agent, preferably an onium cation, resulting in an organoclay containing sulfur. In both media, the sulfur is bonded to the phyllosilicate covalently, ionically, physically, or by a combination of mechanisms.

BACKGROUND AND PRIOR ART

The technologies available for mercury and arsenic removal, such as precipitation, coagulation/co-precipitation, activated carbon adsorption, ion-exchange and the like, are not sufficiently effective for mercury and arsenic (arsenite and arsenate compounds) removal. This assignee’s organoclay has been proven effective on a variety of organic contaminants in the last decade. See, for example, this assignee’s U.S. Pat. Nos. 6,398,951; 6,398,966; 6,409,924; and 6,749,757, incorporated herein by reference. A new Hg/As filtration media, described herein, can be operated in a similar fashion, or together with the organoclay media, but is much more effective for mercury or arsenic removal.

Both Hg/As removal media described herein have a similar physical form to the organoclays used for organic contaminant removal and can be similarly packed in a canister or cartridge, as described in the above-listed patents. In addition, the Hg/As removal media described herein can be deployed in single layer or multi-layer water-permeable mats, as described in this assignee’s published applications Ser. No. 10/718,128, filed Nov. 19, 2003 (Publication No. 2005-01013707 A1), Ser. No. 11/221,019, filed Sep. 7, 2005 (Publication No. 2006/0000767 A1), [Ser. No. 11/489,383, filed Jul. 19, 2006, (Publication No. 2006-0286888 A1)], Ser. No. 11/599,080, filed Nov. 14, 2006 (Publication No. 2007-0059542 A1); and Ser. No. 11/741,376, filed Apr. 27, 2007, all of which are hereby incorporated by reference. Fundamentally, the Hg/As removal media is based on organoclay technology but it has been substantially modified using several unique chemistries to enhance adsorption of mercury and arsenic-containing compounds. The mechanism of mercury adsorption is based upon chemical bonding, ionic bonding,

mechanical bonding, or a combination thereof. The mercury and/or arsenic will be bonded to the media’s external and internal surfaces and the bonding process is non-reversible.

Both Hg/As removal media described herein are effective on all sources of mercury and arsenic including organic types of mercury and arsenic, including organic mercury and arsenic compounds, mercury metal (zero valent); arsenite and arsenate compounds; arsenic ions (both III and V valent); and mercury ions (both I and II valent). When the organic-based mercury and/or arsenic is involved, the adsorption mechanism of partition could be involved in addition to chemical bonding. In addition, both Hg/As removal media described herein also are effective to remove oil, grease and other organic contaminant molecules. The media will be spent eventually when all of the adsorption sites are saturated. The actual media life will depend on the contaminated water compositions and the field operation conditions. When both Hg/As removal media are used together, either in series or admixed, the removal of mercury and/or arsenic is synergistic.

Greco U.S. Pat. No. 5,512,526 describes a clay-based heavy metal removal media prepared by reacting a fatty mercaptan, e.g., dodecylmercaptan, with a fatty alkyl-containing quaternary ammonium compound. As described, the mercaptan’s hydrophobic fatty alkyl group associates in some manner with the fatty alkyl group of the quaternary ammonium compound.

SUMMARY

It has been found in accordance with the present invention that the combined use of (1) a sulfur-impregnated organoclay; and (2) a coupling agent-reacted organoclay, wherein the coupling agent contains sulfur, preferably in the form of a mercapto, disulfide, tetrasulfide and/or other polysulfide functional group (hereinafter called “coupling agent-reacted”) provides mercury and arsenic removal media having increased reactivity, stability, and synergistic mercury and arsenic removal ability. The first (sulfur-impregnated) Hg/As removal media described herein is prepared by impregnating an organophilic clay with elemental (free state) sulfur; and the second Hg/As removal media described herein is prepared by reacting an organophilic clay, preferably containing onium ions, with a sulfur-containing coupling agent, preferably containing a mercapto, disulfide, tetrasulfide, and/or polysulfide moiety. Alternatively, a clay can be made organophilic by treating the clay with a surface-treating agent, such as a polymer capable of increasing the d-spacing of the clay platelets, or preferably with onium ions, prior to or simultaneously with (1) impregnating the resulting organoclay with sulfur, or (2) reacting the organoclay with a sulfur-containing coupling agent.

BRIEF DESCRIPTIONS OF THE DRAWINGS

FIGS. 1 and 2 are graphs showing the mercury removal efficacy of the sulfur-impregnated Hg/As removal media described in the examples;

FIG. 3 is a graph showing the arsenic removal results for the Hg/As removal media of Example 6;

FIGS. 4-6 are graphs showing the mercury removal efficacy of the coupling agent-reacted media described in the examples;

FIG. 7 is a side view of an offshore oil well drilling platform generally showing one or both of the Hg/As removal media held within a canister attached to an offshore oil well drilling platform support structure with an alternative placement of a sump tank;

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FIG. 8 is a sectional view of an embodiment of a vessel containing a plurality of Hg/As removal media-containing cartridges or canisters for efficient removal of mercury and arsenic contained in water;

FIG. 9 is an elevational view of a preferred embodiment of a vessel containing a plurality of Hg/As removal media-containing cartridges or canisters;

FIG. 10 is a top plan view of the header of the vessel shown in FIG. 9 and openings within the header for receiving permeable conduits each of which can extend through a stack of cartridges or canisters as shown in FIGS. 8 and 9;

FIG. 11 is a partially broken-away side view of an embodiment of a Hg/As removal media-containing vessel, containing multiple, stacked cartridges (FIGS. 8 and 9); and

FIG. 12 is an elevational view of a preferred embodiment of a mercury removal media-containing cartridge shown in FIGS. 8 and 9.

It should be understood that the drawings are not necessarily to scale and that the embodiments are sometimes illustrated by graphic symbols, phantom lines, diagrammatic representations and fragmentary views. In certain instances, details which are not necessary for an understanding of the present invention or which render other details difficult to perceive may have been omitted. It should be understood, of course, that the invention is not necessarily limited to the particular embodiments illustrated herein.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

It should be understood that while the following description of the preferred embodiment of the invention is directed to the use of the methods, apparatus and mercury/arsenic removal media on an offshore drilling platform, the invention is also useful for mercury and arsenic removal from any contaminated water, including drinking water; industrial wastewaters; contaminated ground water supplies; aqueous mining wastes; and contaminated underwater and soil sediments, particularly when contained in a reactive mat, as described in the applications identified in paragraph [0003], or when used in bulk form.

The sulfur-impregnated Hg/As removal media described herein is a sulfur-containing layered organophilic phyllosilicate that is (or has been) made organophilic by reaction with an organic phyllosilicate surface-treating agent, preferably an onium ion-liberating compound, and has been made mercury-reactive and arsenic reactive by impregnation with elemental sulfur. The coupling agent-reacted Hg/As removal media described herein preferably is a mercapto- or sulfide-containing layered organophilic phyllosilicate that is (or has been) made organophilic by reaction with an organic phyllosilicate surface-treating agent, preferably an onium ion-liberating compound, and has been made mercury-reactive and arsenic-reactive by bonding a mercapto- or sulfide-containing coupling agent to the phyllosilicate platelets.

Phyllosilicate

The phyllosilicate can be a smectite clay, e.g., bentonite, montmorillonite, hectorite, beidellite, saponite, nontronite, volkonskoite, sauconite, stevensite, and/or a synthetic smectite derivative, particularly fluorohectorite and laponite; a mixed layered clay, particularly rectorite and their synthetic derivatives; vermiculite, illite, micaceous minerals, and their synthetic derivatives; layered hydrated crystalline polysilicates, particularly makatite, kanemite, octasilicate (illierite),

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magadiite and/or kenyaite; attapulgite, palygorskite, sepiolite; or any combination thereof.

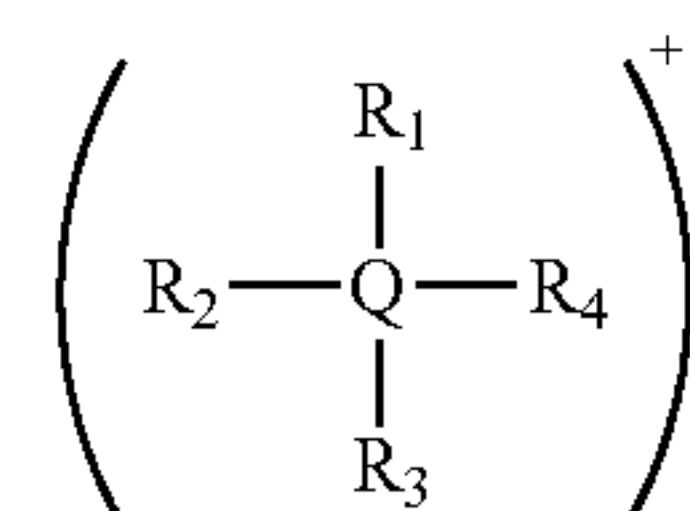
Clay Surface Modification Agents

The surface modification (intercalant) agents used for organoclay formation include but are not limited to primary amine, secondary amine, tertiary amine, and onium ions and/or onium salt compounds, polyquat, polyamine, cationic polymers and their derivatives, nonionic polymers, and mixture of thereof.

In the wet process, the surface modification agent, e.g., onium ion, is introduced into the layered material galleries in the form of a solid or liquid composition (neat or aqueous, with or without an organic solvent, e.g., isopropanol and/or ethanol, if necessary to aid in dissolving the onium ion compound) having a surface modification, e.g., onium ion concentration sufficient to provide a concentration of about 5% to about 10% by weight clay (90-95% water) and the surface modification agent, e.g., onium ion compound, is added to the clay slurry water, preferably at a molar ratio of onium ions to exchangeable interlayer cations of at least about 0.5:1, more preferably at least about 1:1. The onium ion-intercalated clay then is separated from the water easily, since the clay is now hydrophobic, and dried in an oven to less than about 5% water, preferably bone dry. The onium ion surface modification agent compound or polymer can be added as a solid with the addition to the layered material surface modification agent blend of preferably about 20% to about 40% water and/or organic solvent, more preferably at least about 30% water or more, based on the dry weight of layered material. Preferably about 30% to about 40% water, more preferably about 25-35% water, based on the dry weight of the layered material, is included in the onium ion intercalating composition, so that less water is sorbed by the intercalate, thereby necessitating less drying energy after onium ion intercalation.

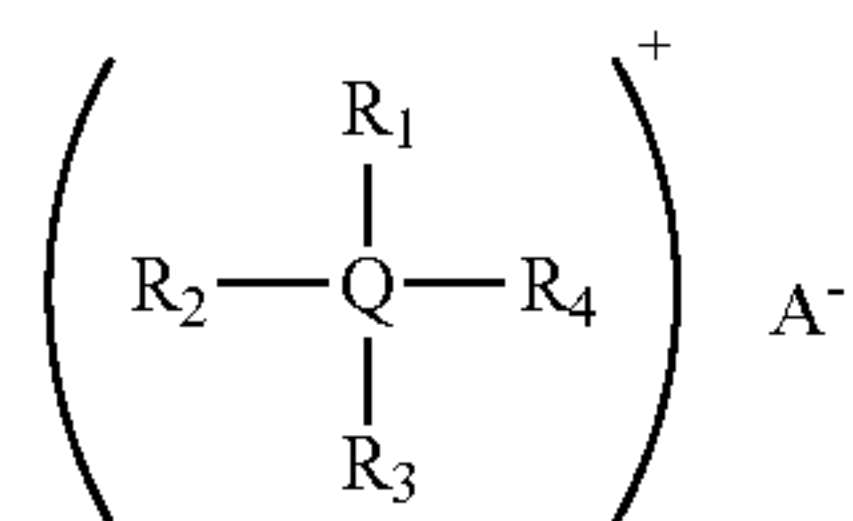
In general, a dry process can be described, as follows, for organoclay media preparation or manufacturing. The powder form of clay mineral is fed into a mixer through a major port for solids, typically an extruder. A separate port for the 2nd powder form of solid can also be used besides the clay feeding port. The liquid forms of the additives, including water, intercalant agent, and the coupling agent if any, are fed into the mixer through the separate ports. Either multiple forms of the solids or the liquids could be pre-mixed, or both the solids and the liquids can be pre-mixed through a separate mixer, before they are fed into the extender. A preferred liquid weight is from 10% to 50% based on the total mixture weight, more preferably from 20% to 40%, most preferably from 25% to 35%. The intimate mixture from the extruder will be further dried through a dryer, and be ground to the preferred particle size. A screening process could be used to collect the finished product in the desired particle size distribution.

The onium ions may generally be represented by the following formula:



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The preferred phyllosilicate surface-treating agent is one or more onium salt compounds, generally represented by the following formula:



wherein Q=N, P, S;

wherein A=halide, acetate, methylsulfate, hydroxide, preferably chloride;

wherein R₁, R₂, R₃ and R₄ are independently organic moieties, or oligomeric moieties or hydrogen. (Ref. U.S. Pat. No. 6,376,591), hereby incorporated by reference. Examples of useful organic moieties include, but not limited to, linear or branched alkyl, benzyl, aryl or aralkyl moieties having 1 to about 24 carbon atoms.

EXAMPLES

bis(hydrogenated tallow alkyl)dimethyl ammonium chloride (Arquad® 2HT); benzylbis(hydrogenated tallow alkyl) methyl ammonium chloride (Arquad® M2HTB); benzyl(hydrogenated tallow alkyl)dimethyl ammonium chloride (Arquad® DMHTB); trihexadecylmethyl ammonium chloride (Arquad® 316); tallowalkyl trimethyl ammonium chloride (Arquad® T-27W and Arquad® T-50); hexadecyl trimethyl ammonium chloride (Arquad® 16-29W and Arquad® 16-50); octadecyl trimethyl ammonium chloride (Arquad® 18-50(m)); and dimethylhydrogenated tallow-2-ethylhexyl ammonium methylsulfate.

Additional phyllosilicate surface-treating agents include the materials set forth below in paragraphs [0024]-[0030].

Quaternary ammonium ions containing ester linkage: (ref. U.S. Pat. No. 6,787,592, hereby incorporated by reference, see columns 5 and 6)

EXAMPLE

di(ethyl tallowalkylate)dimethyl ammonium chloride (Arquad® DE-T).

Quaternary ammonium ions containing amide linkage: (ref. US Patent Application 2006/0166840 hereby incorporated by reference, see page 2)

The onium ions may be functionalized such as protonated α,ε-amino acid with the general formula (H₃N—(CH₂)_n—COOH)⁺.

Alkoxyated quaternary ammonium chloride compounds (ref. U.S. Pat. No. 5,366,647 hereby incorporated by reference)

EXAMPLES

cocoalkylmethylbis(2-hydroxyethyl) ammonium chloride (Ethoquad® C/12); octadecylmethyl[polyoxyethylene(15)] ammonium chloride (Ethoquad® 8/25); and octadecylmethyl (2-hydroxyethyl) ammonium chloride (Ethoquad 18/12).

Polyquat (U.S. Pat. No. 6,232,388, hereby incorporated by reference)

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EXAMPLE

N,N,N',N',N'-pentamethyl-N-tallowalkyl-1,3-propane diammonium dichloride (Duaquad® T-50).

Polyamine: (ref. US patent application 2004/0102332 hereby incorporated by reference)

EXAMPLES

N-tallow-1,3-diaminopropane (Duomeen® T); N-tallow-alkyl dipropylene triamine (Triameen® T); and N-tallow-alkyl tripropylene tetramine (Tetrameen® T).

Cationic polymers, non-ionic polymers, including homopolymer or copolymer, low molecular weight or high molecular weight

EXAMPLE

Polydiallyldimethylammonium chloride; Poly(dimethylamine-co-epichlorohydrin); Polyacrylamide; and Copolymers of acrylamide and acryloyloxylethyltrimethyl ammonium chloride.

Coupling Agent

Examples of the preferred silane coupling agents containing a mercapto, disulfide, tetrasulfide, or polysulfide reactant group or moiety for reaction with the organoclay in manufacturing the coupling agent-reacted Hg/As removal media include, for example, 3-Mercaptopropyltrimethoxysilane; 3-Mercaptopropyltriethoxysilane; 3-Mercaptopropylmethyldimethoxysilane; (Mercaptomethyl)dimethylethoxysilane; (Mercaptomethyl)methyldiethoxysilane; 11-mercaptoundecyltrimethoxysilane; Bis[3-(triethoxysilyl)propyl]-tetrasulfide; Bis[3-(triethoxysilyl)propyl]-disulfide; Bis-[m-(2-triethoxysilyl)ethyl]tolyl]-polysulfide; and mixtures thereof.

Hg/As Removal Media

In a preferred embodiment, particularly in offshore environments, the combined use of both Hg/As removal media described herein can be used after the use of an organoclay for removal of organics in order to protect and extend the active life of both the organoclay, in an initial organoclay stage, and the two Hg/As removal media, used after organic contaminant removal. An operation procedure using an initial organoclay media followed by contact with both of the Hg/As removal media, in series, is highly effective. A carbon media can also be used before or after both Hg/As removal media, if necessary. In general, the retention time of contact between Hg-contaminated or As-contaminated water and each of the Hg/As removal media should be no less than about 10 seconds, preferably at least about 1 minute, more preferably about 2 minutes or more.

The preferred amount of components of the sulfur-impregnated organoclay media is as follows:

	Phyllosilicate	Intercalant Agent	Elemental Sulfur
Preferably	1-90	10-50	0.5-50
More Preferably	35-83	15-45	2-20
More Preferably	50-77	20-40	3-10
More Preferably	59-71	25-35	4-6
Most Preferably	65	30	5

The preferred amounts of components that form the coupling agent-reacted organoclay Hg/As removal media are as follows:

	Phyllosilicate	Intercalant Agent	Coupling Agent
Preferably	1-90	10-50	0.5-50
More Preferably	35-83	15-45	2-20
More Preferably	50-77	20-40	2-12
More Preferably	59-71	25-35	5-9
Most Preferably	65	28	7

Laboratory Study

A column study was conducted in order to demonstrate the sulfur-impregnated Hg/As media's ability to remove mercury (Examples 1-5); arsenic (Example 6); and a combination of mercury and arsenic (Example 7). The influent was composed of ~10 ppm of Hg(NO₃)₂ solution with dilute nitric acid matrix. The effluent samples were taken at regular intervals and the mercury content was measured by an ICP analytical test. The flow rate was about 10 bed volumes (BV) per hour, using a 6-minute retention time. The effluent curve is shown in FIG. 1. A commercial mercury removal media (Hg-A of SME Associates, Houston, Tex.) containing a mixture of 85-90% activated carbon and 10-15% sulfur was also included in this study for comparison purposes, as shown in FIG. 1.

Although only a dry-process is described in the following examples, a wet-process is also suitable as the process to make the sulfur-impregnated mercury media described herein.

Example 1

Sample L1S

400.0 g of bentonite clay (particle size<75 μm preferred, and ~8% moisture content) was dry-mixed with 28.75 g of sulfur in the powder form (purchased from Aldrich) using the Kitchen Aid mixer for one minute. 80.0 g of deionized water was added to this bentonite-sulfur mixture slowly under shearing using the same mixer and mixed for ~2 minutes. 209.6 g of melt quat (ARQUAD® 2HT from Akzo Nobel, bis(hydrogenated tallow alkyl)dimethyl ammonium chloride, ~83% active) was added to this clay-sulfur-water mixture under shearing using the same mixer, and mixed for 5 minutes. The mixture was extruded three times using a laboratory-scale extruder with a die-plate, and the final extrudates were oven-dried at 85° C. to a moisture content of less than 5% by weight. The dried extrudates were ground and resulting particles between 18 and 40 mesh (US standard sieves) were collected and tested for their performance.

Example 2

The media material collected in Example 1 was packed in a column having an inner diameter of 1.5" and having an empty bed volume (BV) of ~86 mL. The influent was composed of ~10 ppm of Hg(II) in the presence of nitric acid. The effluent samples were taken at regular intervals and the mercury content was measured by the Inductively Coupled Plasma (ICP) analytical technique. The flow rate was about 10 BV/hr with a 6-minute retention time. The effluent data is plotted in FIG. 1. A commercial organoclay media Hg-A (without sulfur) is also included in this study for the comparison purpose.

Example 3

Production Trial 1

5 Bentonite powder and sulfur powder (from Harwick Standard Distribution Corporation, grade 104) were blended in a ratio of 93.3:6.7 by weight, and then this mixture was fed into a 5" Readco continuous processor at a feed rate of 900 lb/hr. About 0.25 gallon/minute of water and 1.04 gallon/minute of quat (ARQUAD® 2HT from Akzo Nobel, bis(hydrogenated tallow alkyl)dimethyl ammonium chloride, ~83% active) were also fed in the Readco processor through two independent ports in sequence. The discharged extrudates from the processor were sent to a dryer, the dried extrudates were further milled and the granular particles between 18 and 40 mesh with moisture content less than 5% by weight were collected as the finished product.

Example 4

20 A similar column test as described in Example 2 was conducted on the product sample collected in Example 3. The effluent testing results are plotted in FIG. 2.

Example 5

25 The media described in Example 2 was tested under offshore platform conditions using actual offshore mercury-contaminated water. A commercial available organoclay product, CrudeSorb™, was also used in front of this Hg/As removal media. The influent had a mercury concentration of 11.4 ppb, and the effluent was 3.4 and 3.9 ppb after the 30 minutes and 90 minutes treatment, respectively. A total mercury removal efficiency of >65% was achieved.

35 Arsenic Removal Example

Example 6

40 The media described in Example 3 was examined for its ability to remove arsenic. The media materials were packed in a column with inner diameter of 1.5" and empty bed volume of ~86 mL. The influent solution was composed of ~5 ppm of As(V). The As(V) stock solution was prepared by dissolving Na₂HAsO₄·7H₂O in the de-ionized water. The effluent samples were taken at regular intervals and the arsenic content was measured by the Inductively Coupled Plasma (ICP) analytical technique. The flow rate was around 10 BV/hr with 6-minute retention time. The effluent data is plotted in FIG. 3.

50 Offshore Field Study—Sulfur-Impregnated Media Example for Both Hg and As Removal:

Example 7

55 The sulfur-impregnated media material described in Example 3 was tested under offshore platform conditions using the actual wastewater contaminated by both mercury and arsenic. The contaminated water was pumped through two columns in series. Each column had a diameter of 3" and held about 1.5 Liter of media (~1,125 grams). The first column was packed with the commercial available organoclay media, CrudeSorb™, and the second column was packed the media material described in Example 3. The retention time was roughly equal to 5-minutes. The influent had mercury and arsenic concentration of 11.4 ppb and 7.55 ppb, respectively. After the 30 minutes and 90 minutes treatment, the effluent had mercury concentrations of 3.4 ppb and 3.9 ppb,

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arsenic concentrations of 5.18 ppb and 5.16 ppb, respectively. So a total mercury and arsenic removal efficiency of greater than 65% and 30% were achieved, respectively.

Another column study was conducted in order to demonstrate the coupling agent-reacted Hg/As media's ability to remove mercury (Examples 8-18); arsenic (Examples 19 and 20); and a combination of mercury and arsenic (Example 21). The influent was composed of ~10 ppm of $\text{Hg}(\text{NO}_3)_2$ solution with dilute nitric acid matrix. The effluent samples were taken at regular intervals and the mercury content was measured by an ICP analytical test. The flow rate was about 10 BV/hr using a 6-minute retention time. The effluent curve is shown in FIG. 4. A commercial mercury removal media (Hg-A of SME Associates, Houston, Tex.) containing a mixture of 85-90% activated carbon and 10-15% sulfur was also included in this study for comparison purpose, as shown in FIG. 4.

Although only a dry-process is described in the following examples, a wet-process is also suitable as the process to make the coupling agent-reacted mercury media described herein.

Example 8

Sample L6L

800.0 g of bentonite clay (particle size <75 μm preferred, and ~8% moisture content) was mixed with 160.0 g of deionized water using the Kitchen Aid mixer until a homogenous mixture was obtained. 380.0 g of melt quat (ARQUAD® 2HT from Akzo Nobel, bis(hydrogenated tallow alkyl)dimethyl ammonium chloride, ~83% active) was added to this bentonite-water mixture under shearing using the same mixer, and mixed for 5 minutes. 40.0 g of the silane agent (Silquest® A-189 from GE Silicones, gamma-Mercaptopropyltrimethoxysilane) was pre-mixed with 20.0 g of ethanol and 2.0 g of water. This fresh prepared solution was added to the above clay-water-quat mixture, and mixed for 5 minutes. This mixture was extruded three times using a laboratory-scale extruder with a die-plate, and the final extrudates were oven-dried at 85° C. to a moisture content of less than 5% by weight. The dried extrudates were ground and resulting particles between 18 and 40 mesh (US standard sieves) were collected and tested for their performance.

Example 9

Sample L6L2

Very similar preparation procedure was conducted except 80.0 g of the silane agent was pre-mixed with 80.0 g of ethanol and 8.0 g of water, and was subsequently added to clay-water-quat mixture.

Example 10

Sample L6L3

800.0 g of bentonite clay (particle size <75 μm preferred, and ~8% moisture content) was mixed with 160.0 g of deionized water using the kitchen Aid mixer until a homogenous mixture was obtained. 60.0 g of the silane agent (Silquest® A-189 from GE Silicones, gamma-Mercaptopropyltrimethoxysilane) was mixed with 380.0 g of melt quat (ARQUAD® 2HT from Akzo Nobel, bis(hydrogenated tallow alkyl)dimethyl ammonium chloride, ~83% active), and this mixture was added to the bentonite-water mixture under shearing using the same mixer, and mixed for 5 minutes. This

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mixture was extruded three times using a laboratory-scale extruder with a die-plate, and the final extrudates were oven-dried at 85° C. to a moisture content of less than 5% by weight. The dried extrudates were ground and resulting particles between 18 and 40 mesh (US standard sieves) were collected and tested for their performance.

Example 11

The media material collected in Example 1 was packed in a column with an inner diameter of 1.5" and having an empty bed volume (BV) of ~92 mL. The influent was composed of ~10 ppm of Hg(II) in the presence of nitric acid. The effluent samples were taken at regular intervals and the mercury content was measured by the Inductively Coupled Plasma (ICP) analytical technique. The flow rate was about 10 BV/hr with a 6-minute retention time. The effluent data is plotted in FIG. 4. A commercial organoclay media is also included in this study for the comparison purpose.

Examples 12, 13

Column tests were also conducted on the organoclay media materials collected from Examples 9 and 10. The results are also plotted in FIG. 4.

Example 14

A column test was conducted on the organoclay media collected in Example 9. The influent was composed of ~10 ppm of Hg(II) and ~8 ppm of mechanical emulsified motor oil. The oil concentration in influent and effluent was characterized by Total Oil & Grease (TOG) analytical test. Throughout the test, the TOG for effluent was maintained at 0 ppm. The effluent results on mercury were plotted in FIG. 5.

Example 15

A column test was conducted on the organoclay media collected in Example 9. The influent was composed of 224 ppb of Hg(II). The effluent samples were taken at 9.4, 18.9, 28.3 Bed Volume intervals and their mercury concentration were 1.2 ppb, 0.8 ppb and 0.3 ppb, respectively. The mercury measurement tests were conducted by Test America (Buffalo Grove, Ill.) using EPA 245.2 test method.

Example 16

Sample Production Trial 2

Bentonite powder was fed into a 5" Readco continuous processor at a feed rate of 600 lb/hr. About 0.40 gallon/minute of water and 0.78 gallon/minute of combined mixture of quat and silane coupling agent were also fed in the Readco processor through two independent ports in sequence. The mixed ratio between the quat (ARQUAD® 2HT from Akzo Nobel, bis(hydrogenated tallow alkyl)dimethyl ammonium chloride, ~83% active) and the silane coupling agent (Silquest® A-189 from GE Silicones, gamma-Mercaptopropyltrimethoxysilane) was about 82.6:17.4 by weight. The discharged extrudates from the processor were sent to a dryer, the dried extrudates were further milled and the granular particles between 18 and 40 mesh with a moisture content less than 5% by weight were collected as the finished product.

Example 17

A similar column test as described in Example 11 was conducted on the product sample collected in Example 16. The effluent testing results are plotted in FIG. 3.

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Example 18

The Hg/As removal media described in Example 16 was tested under offshore platform conditions using the actual offshore mercury contaminated water. A commercially available organoclay product, CrudeSorb™, was also used in front of this Hg/As removal media. The influent had a mercury concentration of 37.7 ppb, and the effluent was 2.8 and 4.2 ppb after the 30-minute and 90-minute treatment, respectively. A total mercury removal efficiency of >88% was achieved.

Arsenic Removal Example

Example 19

The media described in Example 16 was examined for its ability to remove arsenic. The media materials were packed in a column having an inner diameter of 1.5" and empty bed volume of ~86 mL. The influent solution was composed of ~5 ppm of As(V). The As(V) stock solution was prepared by dissolving Na₂HAsO₄·7H₂O in the de-ionized water. The effluent samples were taken at regular intervals and the arsenic content was measured by the Inductively Coupled Plasma (ICP) analytical technique. The flow rate was around 10 BV/hr with 6-minute retention time. During 90 bed volume treatment, the average effluent concentration was 3 ppm for a 40% removal of arsenic by the media.

Offshore Field Study Example for Both Hg and As Removal:

Example 20

The media material described in Example 16 was tested under offshore platform conditions using the actual wastewater contaminated by both mercury and arsenic. The contaminated water was pumped through two columns in series. Each column had a diameter of 3" and held about 1.5 Liter of media (~1,125 grams). The first column was packed with the commercial available organoclay media, CrudeSorb™, and the second column was packed the media material described in Example 9. The retention time was roughly equal to 5-minute. The influent had mercury and arsenic concentration of 37.7 ppb and 8.17 ppb, respectively. After the 30 minutes and 90 minutes treatment, the effluent had mercury concentrations of 2.8 ppb and 4.2 ppb, arsenic concentrations of 5.70 ppb and 5.87 ppb, respectively. So a total mercury and arsenic removal efficiency of greater than 88% and 28% were achieved, respectively.

Example for Sulfur-Impregnated Media and Coupling Agent-Reacted Media Combined Use:

Example 21

The sulfur impregnated organoclay media and the coupling agent-reacted organoclay media were tested as a package using the actual wastewater contaminated by both mercury and arsenic species on an offshore platform. The contaminated water was pumped through two columns in a series operation. Each column had a diameter of 3" and held about 1.5 Liter of media (~1,125 grams). The first column was packed with the sulfur impregnated organoclay media as described in Example 3, and the second column was packed with the coupling agent-reacted organoclay media as described in Example 16. The retention time was roughly equal to 5-minute. The influent had mercury and arsenic concentrations of 26.8 ppb and 10.68 ppb, respectively. After

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the 30 minutes treatment, the effluent had mercury and arsenic concentrations of 2.4 ppb and 2.15 ppb, respectively. So a total, and synergistic mercury and arsenic removal efficiency of greater than 91% and 79% were achieved, respectively.

Turning now to the offshore drawings, and initially to FIG. 7, there is shown an offshore drilling platform generally designated by reference numeral 10 including a work deck support structure 12 for supporting a plurality of stacked work decks at a substantial height above an ocean water level 14. The work decks commonly include a cellar deck 16 at a lowest work deck level, a second deck 18 located directly above the cellar deck 16, a third deck 20 disposed directly above deck 18, and a main deck 22 at an uppermost work deck level. In extant offshore drilling platforms, a sump tank 24 has been connected to the drilling platform 10 at the cellar deck level 16 and rainwater, including entrained hydrocarbons, particularly oil, paraffins and surfactants have been directed from all deck levels, which are contained so that rainwater and entrained hydrocarbons do not spill over to the ocean, to drain by gravity into the sump tank 24. As described in this assignee's U.S. Pat. Nos. 6,398,951; 6,398,966; 6,409,924; and 6,749,757, hereinafter incorporated by reference, further separation of hydrocarbons from rainwater, in addition to gravity separation, is required for effective elimination of ocean water hydrocarbon contamination by providing a secondary hydrocarbon recovery apparatus containing an organo-clay after the produced water and/or rainwater has been separated by gravity in the sump tank 24 or 24A. In the preferred embodiment of mercury and/or arsenic removal using the methods and apparatus described herein for mercury and arsenic removal offshore, one or more canisters (not shown) containing an organoclay, for hydrocarbon removal, is used in series with one or more canisters containing the Hg/As removal media (in any order). It is preferred to remove the hydrocarbons with organoclay-containing canister(s) prior to mercury and/or arsenic removal with Hg/As removal media-containing cartridges.

In accordance with a preferred embodiment of the methods, apparatus and Hg/As removal media described herein, it has been found that the apparatus and methods described herein function best, in offshore platform use, when the sump tank 24A is disposed on or near a boat landing deck level 26 (FIG. 7) of the offshore drilling platform 10. However, the sump tank can also be disposed at an upper level, such as at reference numeral 24 in FIG. 7.

Mercury and/or arsenic from ocean water that is collected on the production decks 16, 18, 20 and 22 that may accumulate during dry weather on the inner surfaces of the conduit 28 and inner surfaces of sump tank 24 can be separated from the water that flows from the decks to the Hg/As removal media-containing cartridge 44 for recovery and separation in accordance with the apparatus and methods described herein.

Water containing mercury and/or arsenic is conveyed via conduit 28 from the deck areas 16, 18, 20 and 22 along the platform infrastructure or support leg 12 down to the sump tank 24 or 24A, preferably sump tank 24A for convenient servicing and/or Hg/As removal media cartridge replacement. As stated in this assignee's U.S. Pat. Nos. 6,398,951, 6,398,966 and 6,409,924, it is expedient to dispose the separation apparatus described herein at or near the boat landing deck level 26 (such that at least a portion of the sump tank 24A is within about 10 feet of ocean level) since contaminants collected on the production decks 16, 18, 20 and 22 that may accumulate during dry weather on the inner surfaces of the conduit 28 and inner surfaces of sump tank 24A can be separated from the water that flows from the decks to the

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sump tank 24A for recovery and separation in accordance with the apparatus and methods described herein.

In accordance with an important feature of the methods, apparatus and mercury removal media described herein, a downwardly extending leg portion 42 of water leg 34 is operatively interconnected to, and in fluid communication with, one or more mercury and/or arsenic media-containing vessels 44. As shown in FIG. 8, the mercury removal media within vessel 44 captures the mercury and thereby separates essentially all mercury from the water (less than about 10 parts per million, preferably less than about 1 part per million mercury remains). The treated water flows through the liquid-permeable covers 76 of the cartridges 55 into the vessel 44. The treated water then flows by gravity through water exit opening 46 in the water and coalesced hydrocarbon collection vessel 44 and through exit conduit 48 back to the ocean water 14.

As shown in FIGS. 8 and 9, vessel 44 includes an outer, fluid-impermeable housing 48 having a water inlet 42 interconnected through the housing 48 so that mercury-contaminated water enters vessel 44 and then flows through the Hg/As removal media-containing cartridges 55, through a plurality of longitudinal, axial, central inlet conduits 56, 56A, 56B, 56C and 56D that may form part of a header, described in more detail hereinafter. The mercury removal media-containing cartridges 55 are water-permeable by virtue of flow apertures 57, in the cartridge cover 76, that are sized sufficiently small such that the mercury removal media does not pass therethrough. Water entering vessel 44 through inlet conduit 42 and cartridge inlet conduits 56, 56A, 56B, 56C and 56D flows radially outwardly through the mercury removal media 45 where the mercury removal media captures, and removes, the mercury from the contaminated water. The purified water flows through the openings 57 in each liquid permeable cartridge cover 76 and collect in vessel 44. The clean water exits the vessel 44 through exit conduit 69 and through valve 71 and then is returned to the ocean 14 via outlet 73.

Turning to FIG. 9, another embodiment of a vessel 100 is shown containing stacks of cartridges, one of which is shown at 102. Each cartridge stack includes a plurality of annular cartridges 104 through which a porous contaminated liquid inlet conduit 106 extends. The porous inlet conduit 106 is connected to a header 108 which is disposed within a bottom section 110 of the vessel 100, similar to the contaminated water inlet conduits 56, 56A, 56B, 56C and 56D shown in FIG. 8.

Turning to FIGS. 9 and 10, the header 108 is connected to a mercury-contaminated water inlet 112 which includes a flange 114 which is connected to the flange 116 of the header 108 by a plurality of fasteners, such as bolts (not shown). The header is also supported within the bottom structure 110 (see FIG. 9) of the vessel by a plurality of supports shown at 118. The header 108 includes a plurality of openings 120, each of which receives a permeable conduit 106 (see FIG. 9). In the embodiment illustrated in FIGS. 9 and 10, the header 108 is connected to 23 permeable conduits and therefore supports 23 stacks 102 of cartridges 104. By providing the header 108 within the bottom structure 110 of the vessel 100, a permeable tube sheet 111 shown in FIG. 8 is not needed for collecting solids and the bottom section 110 of the vessel can be used to collect accumulated solids, or solids which do not pass through the outer covers 76 of the filter cartridges 104. A drain 122 is provided for purposes of flushing out the accumulated solids which settle in the bottom structure 110 of the vessel 100, together with the clean water. The clean water can be

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passed through a solids filter 123 before being directed to the ocean through conduit 125. In contrast, solids will accumulate on top of the tube sheet 111. Thus, the solids must be removed from above the tube sheet 108 using one or more nozzle openings shown at 109 in FIG. 8. As shown in FIG. 9, these additional nozzle openings are not required in the vessel 100 because the accumulated solids are easily flushed down the drain pipe 122 into solids filter 123.

As shown in FIG. 9, an extremely dense number of stacks of cartridges 104 is provided by the header 108. Specifically, the header 108, as shown in FIG. 10, includes 23 openings 120, and therefore 23 porous conduits 106 and therefore 23 stacks 102 of cartridges 104. Accordingly, the volumetric flow rate that can be handled by the vessel 100 is substantially greater than the volumetric flow rate that can be handled by the vessel 44. Of course, smaller vessels with fewer stacks of cartridges and large vessels with more stacks of cartridges are anticipated.

FIGS. 11 and 12 illustrate a single cartridge 55 containing the Hg/As removal media 45 that is loosely packed within the canister 55 between liquid-permeable contaminated water inlet tube (56, 56A, 56B, 56C and 56D of FIG. 6) and an outer, liquid-permeable cartridge cover 76. As shown, the mercury removal media 45 comprises an organoclay containing sulfur.

What is claimed:

1. A method of removing mercury and/or arsenic from water comprising contacting the water with an intimate mixture of A) sulfur impregnated organoclay and B) a sulfur-containing coupling agent-reacted layered phyllosilicate.

2. The method of claim 1, wherein the coupling agent includes a mercapto or sulfide moiety.

3. The method of claim 1, wherein the weight percentage of components in each of the sulfur-impregnated organoclay and the coupling agent-reacted layered phyllosilicate is as follows:

A) 1) organoclay: 50 to 99.5 wt.%; and

2) elemental sulfur: 0.5 to 50 wt. %;

B) 1) layered phyllosilicate: 50 to 99.5 wt.%; and

2) coupling agent: 0.5 to 50 wt.%.

4. A method of claim 1, wherein the organoclay comprises a layered phyllosilicate intercalated with a phyllosilicate intercalant agent, and wherein the percentage of components is as follows:

A) 1) organoclay: 50 to 99.5 wt.%; and

2) elemental sulfur: 0.5-50 wt.%;

B) 1) layered phyllosilicate: 1-90 wt.%; intercalant agent: 10-50 wt.%; and

2) coupling agent: 0.5-50 wt.%.

5. A method of regenerating contaminated water containing organic and mercury or arsenic contaminants comprising: contacting the contaminated water with an organoclay for removal of organic contaminants; and

contacting the contaminated water with an intimate mixture of A) sulfur impregnated organoclay and B) a sulfur-containing coupling agent-reacted layered phyllosilicate for removal of mercury or arsenic contaminants.

6. The method of claim 5 wherein the organoclay and each contaminant removal media A) and B) are contained in separate vessels connected in series.

7. The method of claim 5 wherein the organoclay and both contaminant removal media A) and B) are contained in the same vessel.

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